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INTERNATIONAL CRYOGENIC ENGINEERING CONFERENCE (4TH) HELD AT EINDHOVEN, NETHERLANDS, ON MAY 24-26, 1972

Robert A. Hein, et al

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FOURTH INTERNATIONAL CRYOGENIC ENGINEERING CONFERENCE
MAY 24-26, 1972

ROBERT A. HEIN* and E. A. EDELSACK
(Dr. Hein is with the Naval Research Laboratory)

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13 ABSTRACT

The fourth International Cryogenic Engineering Conference was held in May, 1972 at the Technical University of Eindhoven, Netherlands. These meetings bring together engineers and scientists of widely differing backgrounds who share a common interest of exploring new uses of cryogenic instrumentation and techniques. There were some 450 delegates from 28 countries. This report reviews many of the papers presented and discusses various research being carried out at various laboratories.

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FOURTH INTERNATIONAL

CRYOGENIC ENGINEERING CONFERENCE

24 - 26 May, 1972, Eindhoven, Holland

I. Introduction

ICEC is the acronym for "International Cryogenic Engineering Conference". This series of conferences, the fourth of which is the subject of this report (ICEC-4), was initiated by Dr. K. Mendelssohn of Oxford University and Professor K. Oshima of Tokyo University. ICEC-1, held in Kyoto, Japan in 1966 and ICEC-2, held in Brighton, England in 1968 were experimental ventures in the international exchange of information in the rapidly developing field of cryogenic engineering.[1] The success of these two meetings stimulated the formation of an international ICE Committee of 12 members to assure continuation of these biennial events. Dr. K. Oshima and Dr. B. Birmingham (USA) are the two non-European members. ICEC-3 was held in West Berlin in 1970 and ICEC-4 was held in May, 1972 in Eindhoven, Netherlands. ICEC-5 will be held in Japan in 1974 and ICEC-6 will be held at Grenoble, France.

The genesis of the ICEC's was a growing awareness in the early 1960's by many European and Asian scientists and engineers that the established cryogenic industry in Europe was beginning to lag behind US efforts and was in danger of missing out on important new developments in low temperature engineering. One of the goals of ICEC was to offset the imbalance of information on cryogenic engineering advances which since the early 1950's had become largely concentrated in two meetings held in the US: the annual Cryogenic Engineering Conference (CEC) and the biennial Applied Superconductivity Conference (ASC). It is anticipated that future ICEC and CEC meetings will be held in alternate years. In this way there will be no more than one big cryogenic engineering conference each year and not more than one of them every two years on either side of the Atlantic.

The ICEC's bring together engineers and scientists of widely differing backgrounds who share the common interest of exploring new uses of cryogenic instrumentation and techniques. This has led to a broad spectrum of talks necessitating several parallel sessions. However, the plenary sessions, special evening sessions and the ever present "coffee break" allow, in principal, engineers and physicists to discuss problems of mutual interest with, for exampl surgeons who are using cryoscalpels. (Occasionally surgeons have been helpful in administering first aid to an inquisitive scientist who has fainted during the viewing of realistic colored, detailed close-up movies of surgical operations with cryoscalpels.)

The site of this three-day meeting was the Technical University of Eindhoven, situated along the River Dommel. This institution is the Netherland's second youngest technical university (see Appendix A). The first day included a morning of invited talks (see Appendix B) with the afternoon meetings given over to 10-minute contributed papers. Each afternoon meeting consisted of three paralleling sessions. Questions concerning the contributed papers, approximating five or six in each session, were deferred until the end of the session at which time the speakers formed a panel to answer questions directed to them as individuals or to the panel as a group. (This approach stimulated much interesting and worthwhile discussion and should be used more frequently at large meetings where time is limited.) The second and third days were slight variations of this general scheme.

There were some 450 delegates from 28 countries. While the number of attendees was comparable to ICEC-3 (West Berlin, 1970), the number of participating countries was increased from 22. This was the first time that scientists from the People's Republic of China participated in an international meeting of this type. A survey of the lists of attendees indicate that the US delegation had increased from about 17 in 1970 to 25 in 1972, despite cuts in available funds for foreign travel.

It is planned to publish the proceedings of ICEC-4 by the end of 1972. They may be ordered from IPC Science and Technology Press Limited, 32 High Street, Guildford, Surrey, England for £14.00 ($35.00).

II. Discussion

A. Uses of Low Temperatures

The honor of being the first speaker went to Prof. A. Lacaze, Centre de Recherches sur les très basses Temperatures, Grenoble. Prof. Lacaze discussed "Trends in the Use of Very Low Temperature Refrigeration". Following a short history of low temperature production he emphasized that the temperature range from 1 to 20K had not yet been exploited by industrial applications. He noted that success in applying cryogenic temperatures in the area of telecommunications (masers and parametric amplifiers), space explorations and cryopumping has done a great deal to spur the development of improved cryogenic refrigerators. This, in turn, has made cryogenic systems less objectionable to engineers.

Superconductivity, he felt is the best candidate for wide scale cryogenic applications. To substantiate this statement he cited the increasing demands for electrical power, higher magnetic fields and high speed ground transportation. He stated that while a large increase in the critical temperature, T_c, of superconductors does not now seem

possible (highest accepted value for T_c is $\approx$21K) increases up to 10 or 20%, which are not impossible, would probably bring out a technical revolution in several aspects of the electrical energy industry. This statement is rather puzzling as it is difficult to see how T_c of 23 or 25K per se would bring about any technological revolution. (See IEE Review Aug. 1972, "Superconductivity and its applications to power engineering".)[2]

Prof. Lacaze finished on the optimistic note that the next decade would see superconducting power lines and generators. He also suggested that the availability of magnetic fields up to 10T make attractive the use of adiabatic demagnetization starting from the 20-30K range of temperatures. (We are skeptical that such a scheme will ever be widely used to produce temperatures in the 4 to 20K range.) Lacaze also noted that it would be interesting to use liquid hydrogen for ground transportation to reduce air pollution. This point was again brought up in a later session.

Prof. H. G. Nöller, Teybold Heraeus Gmbh & Co., discussed "Why Cryopumping". Simply stated, there are two reasons: (1) a very clean vacuum and (2) high pumping speed. (10^5 L/sec can be economically produced.)

After a discussion of the formulae which govern the ultimate vacuum and pumping speeds, he cited specific areas of application of cryopumps: plasma research, space research, electron microscopy and airborne mass spectroscopes. The pumps described by Nöller operate from a liquid helium reservoir and are quite costly to operate (20 times more expensive than a conventional diffusion pump system). Thus they are only employed when their specific advantages (high pumping speed and/or clean vacuum) are required. He presented a cost analysis for an integrated system -- cryopumps and cryogenic refrigerator -- as a function of the pumping speed. He concluded that for pumping speeds in excess of 30,000 L/sec the integrated cryopump is a superior system. He believes the future of cryopumps and their wide application depends upon the development of integrated units which require a few watts of refrigeration at 20K. He showed a slide comparing costs of conventional diffusion pump system versus an integrated cryopump system. (See Fig. 1)

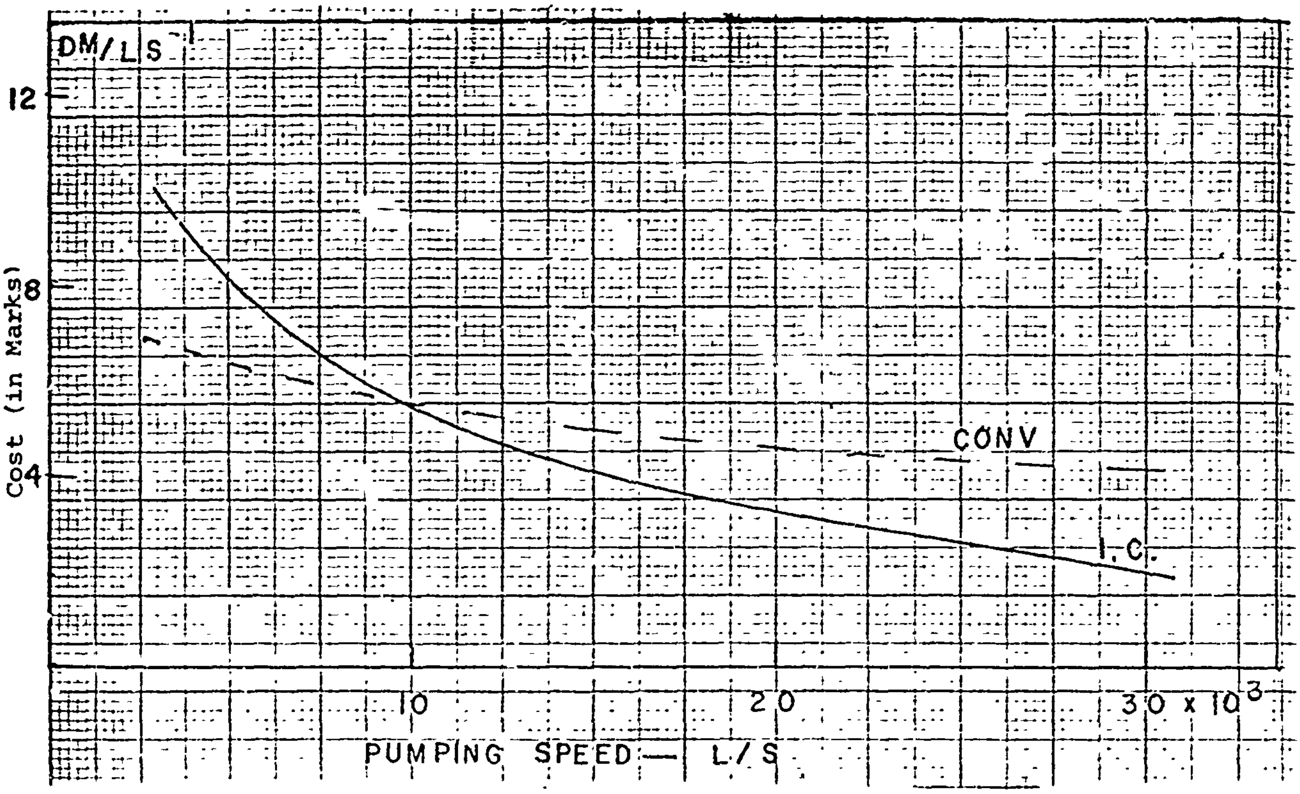

Fig. 1*

Mr. W. H. Hogan , CT Inc., Waltham, Mass., USA, discussed "Helium Conversation in the USA". He stated that the energy crisis in the US, prime supplier of helium gas for the world, is a compelling factor in the present and future supply of helium in the US. This follows from the fact that the increased demands for natural gas, regardless of its helium content, requires that helium be drawn out of the ground at a rate considerably in excess of current or projected demands. The present US conservation program can store no more than 10% of the helium gas which is presently being drawn from the earth.

Hogan then briefly reviewed how the population explosion will lead to even greater demands on the power industry with the concomitant waste of helium gas. What has all this to do with cryogenics? Hogan answered this rhetorical question by stating that while cryogenic R & D uses but a small fraction of the helium consumed in the world, such R & D is more sensitive to the price of helium than

*3.2 German Mark (DM) = $1.00 (US)

any other end use. He emphasized that it would indeed be comforting to know that if current cryogenic R & D efforts were to lead to realizable large scale applications, there would still be helium available for their exploitation. He then briefly discussed the US Conservation Program[3] which was enacted in 1960. The intent of the Conservation Act was that it be a self-liquidating expenditure. However, the increase in privately owned helium plants (from 1 in 1960 to a present-day total of 8) has negated the self-liquidating expenditure aspect of the Conservation Act. This has led the US Department of Interior to contemplate cancelling the conservation program.

At the present time the government has stockpiled 1,300 million equivalent liquid liters of helium, four times the amount consumed in the 1960's. US consumption is currently 40 million equivalent liquid liter of helium per year and the projected growth rate is about 7% per year.

The point to Hogan's remarks is that he estimates that the increased demand for power will deplete our fossil fuels in less than 100 years. Thus he feels we must turn to the development of alternate sources of energy and alternate distribution systems. Many such proposed systems involve massive R & D programs which depend on cryogenics and must consume helium gas almost without limit in order to be effective. This means plundering the easy-to-reach helium reserves beneath the earth, leaving future generations to extract the helium gas from our atmosphere. In summation, we must push ahead with our R & D work involving large scale applications of cryogenics (superconductivity) and at the same time the government should not pay to stockpile helium gas but rather should start a massive R & D program aimed at developing an economical process to extract helium from the atmosphere. Hogan stated that our atmosphere, up to about 500 miles, has about 5 ppm of helium. The helium content of the atmosphere is constant in time so that we have plenty of helium gas present in our atmosphere. We must develop a cheap way to extract it. Current cost to extract helium from the atmosphere is about $40 to $80 per liter.

The contributed papers were then presented in three parallel sessions. Since our greatest interest is superconductivity, we attended those sessions dealing with this subject.

B. Materials

1. Non-Superconducting

Development programs now in progress concerned with rotating electrical machinery which operate at liquid helium temperatures have

focused attention on the low temperature physical properties of certain structural steels and insulating materials. At the Rutherford Laboratory England, investigation[4] of the martensitic transformation of austenite γ to α' phase which occurs in certain grades of stainless steels has been in progress for some time. Interest stems from the fact that a volume expansion follows the transformation as well as the fact that the α' phase is ferromagnetic. The volume expansion could play havoc with machine integrity and clearance tolerances. The most striking result of their work to date is that nitrogen present in the steels to about 2% inhibits the γ to α' transformation. Standard grades of stainless such as AISI 302, 303, 304, etc., contain only $\approx$ 0.03%N, and the γ to α' transition is known to occur in some, if not all, of these steels. This latter work was performed in the Metallurgy Department of Imperial College and was presented by Dr. D. C. Larbalestier.

The other problem cryomachinery faces is the long-time physical stability and electrical breakdown strengths of insulating materials when subjected to a cryogenic environment. Dr. E. Javorsky of Bratislava, Czechoslovakia reported on the results of research concerned with the mechanical and electrical properties of such insulating materials which are used for the "potting" of coils, reinforcing materials and electrical insulation in cryomachinery (i.e., polymers, varnishes, foils, etc.). The reader is referred to the proceedings for detailed results, however, we do want to mention that Javorsky concluded that there is a lack of knowledge about the long-time application of these materials. The aging of electrical insulating materials in cryogenic conditions in electrical fields and its dependence on physical properties is an area that requires considerable attention. Thus, design engineers should take heed.

2. Superconducting

Three papers concerned with the fabrication of technologically important superconducting materials were presented.

Dr. J.H.P. Watson, Corning Glass Works, Corning, New York, USA, discussed the various technical problems and possible solutions, concerned with fabricating useful conductors out of Pb-Bi (40%) impregnated glass fibers. Watson's discovery that Vycor glass could be used to prepare high J_c and H_c filaments of Pb-Bi has, on occasion, been noted as perhaps the only really new development in the area of superconducting materials which has occurred in the last several years. While work with Vycor glass has been going on for some time, the ability to fabricate

km lengths of glass fibers (60 μm in diameter) with pore diameters of approximately 35 Å impregnated with Pb-Bi is a relatively recent development. The Pb-40%Bi has a T_c of about 7.8K, and when prepared as mentioned above, H_{c2} (4.2K) is about 125kG. Typically $J_c \approx 10^5 A/cm^2$ in zero field and $\approx 10^4 A/cm^2$ in a field of 90 kG Watson stated these values can be improved, for example, H_{c2} = 150kG (20 Å pore glass). He has prepared transposed conductors by first weaving the fibers into a braid, which approximates a Litz configuration, leaching the fiber to create the pores, and then impregnating the glass with Pb-Bi. Watson is currently working with 10-μm fibers. A cost figure of $20/km for a conductor of 0.02" diameter (50% of cross section being superconducting) was mentioned.

Watson calculated that the losses of a conductor made up of 10-μm fibers in a 60-Hz peak field of 10^4 Gauss would only be 5.2 x 10^{-2} W/m. It was not clear from Watson's remarks as to whether Corning Glass is planning to pursue the actual fabrication of this material on the scale required for commercial exploitation.

Dr. R. A. Popley (Imperial Metal Industries, Ltd., England) presented a paper titled "A New 13,255 Filament Superconducting Composite". Imperial Metal Industries (IMI) in collaboration with the Rutherford High Energy Laboratory has been developing filamentary superconducting composites which combine low hysteresis loss with good thermal and electrical stability when used in magnets which are pulsed once every few seconds. An essential feature of this new composite is that niobium-titanium filaments are surrounded by a complex matrix having an anisotropic electrical resistivity. The copper which surrounds the individual strands of superconductors are subdivided into cells by an array of resistive cupro-nickel barriers. Magnetization measurements show that for a given twist pitch (the filaments must be twisted about the central axis of the cable to decouple individual filaments) and given level of hysteresis loss, this new conductor can accept $|\dot{H}|$ about four times higher than the early NIOMAX-TC composites. Since this new conductor can carry a critical current of 430 amperes at 5 Tesla (we assume at 4.2K), it is now reasonable to consider cable configurations which require only a small number of superconducting strands. We believe that this composite represents a significant improvement, and if IMI can produce it so that it is economically attractive to the engineers, it will undoubtedly play an important role in the design and fabrication of superconducting magnets and rotating electrical machinery.

C. Ac Losses in Superconductors

The element Nb plays an important role in the area of superconductivity. It has the highest T_c of any element ($\approx$ 9.3K). Its binary compounds Nb_3Sn, Nb_3Al and Nb_3Ga have the highest T_c of any binary system (18.5, 19.1, and 20K, respectively), while a Nb based ternary compound $Nb_{75}(GeAl)_{25}$ has the highest T_c of any well-established superconductor, namely 20.7K. Nb is also an intrinsic Type II superconductor, a distinction it shares with only two other elements, namely, V and Tc Thus, it is not surprising that many physicists, metallurgists and engineers are still probing the transport properties of this element and attempting to correlate these properties with some physical or chemical property of the samples under investigation.

Drs. P. R. Brankin and P. G. Rhodes of the University of Warwick, England, reported results of their continuing program to study ac losses (50 Hz) in Nb as a function of surface preparation, degree of cold working and interstitial impurities. They attribute the spread in published results of ac losses to poor characterization of the samples on which the data were obtained.

Results for ac losses above and below H_{c1} were presented for neutron irradiated, ion implanted and cold-worked samples. These results show that cold-working is far more effective in reducing the losses than are high doses (10^{20} neutron/cm^2) of fast ($>$ 1 MeV) neutrons. They found that mechanical polishing of Nb results in lower ac losses than does electro-polishing. Losses for field values less than H_{c1} are attributed to surface asperities, and they conclude that for small ac losses ($H < H_{c1}$) one needs the surface irregularities to be less than 0.03µm in size. It was also concluded that the high defect structure which is most desirable for low ac loss ($H > H_{c1}$) is most easily attained via mechanical means. This defect structure gives rise to some surface critical state that inhibits flux penetration until $H = H_{FP} > H_{c1}$. Thus, ideally ac losses should be zero until $H = H_{FP}$. In an earlier report [5,6] they showed that H_{FP} of mechanical polished single crystal of Nb was 2000 Oe as compared to an H_{c1} of 1400 Oe. Obviously, then, one wants to find ways to retain the high H_{FP} values and at the same time reduce the non-ideal losses for fields below H_{FP} which are caused by surface asperities.

Dr. C. S. Furtado, Laboratory de Fisica Universidade de Coimbra, Portugal reported on work he did at the Clarendon Laboratory, Oxford University, England. He measured H_{FP} and ac losses (80 Hz) on cylinders of pure Nb containing different amounts of pinning sites. (Experimental details reported in Cryogenics 7). Furtado finds that $H_{FP} = H_{c1}$ and does not exceed H_{c1} as indicated by other workers who say that $H_{FP} = H_{c1} + \Delta H$, $\Delta H > 0$. The fact that $H_{FP}(T)$ shows a parabolic temperature dependence $H_{FP} \simeq 1 - t^2$ where $t = T/T_o$, leads Furtado to conclude that one sees the "reaction" of the surface (i.e., the ΔH term) only after flux has entered the sample, i.e., $H > H_{c1}$.

This study of the ac losses (80 Hz) as a function of temperature resulted in the data shown in Fig. 2.

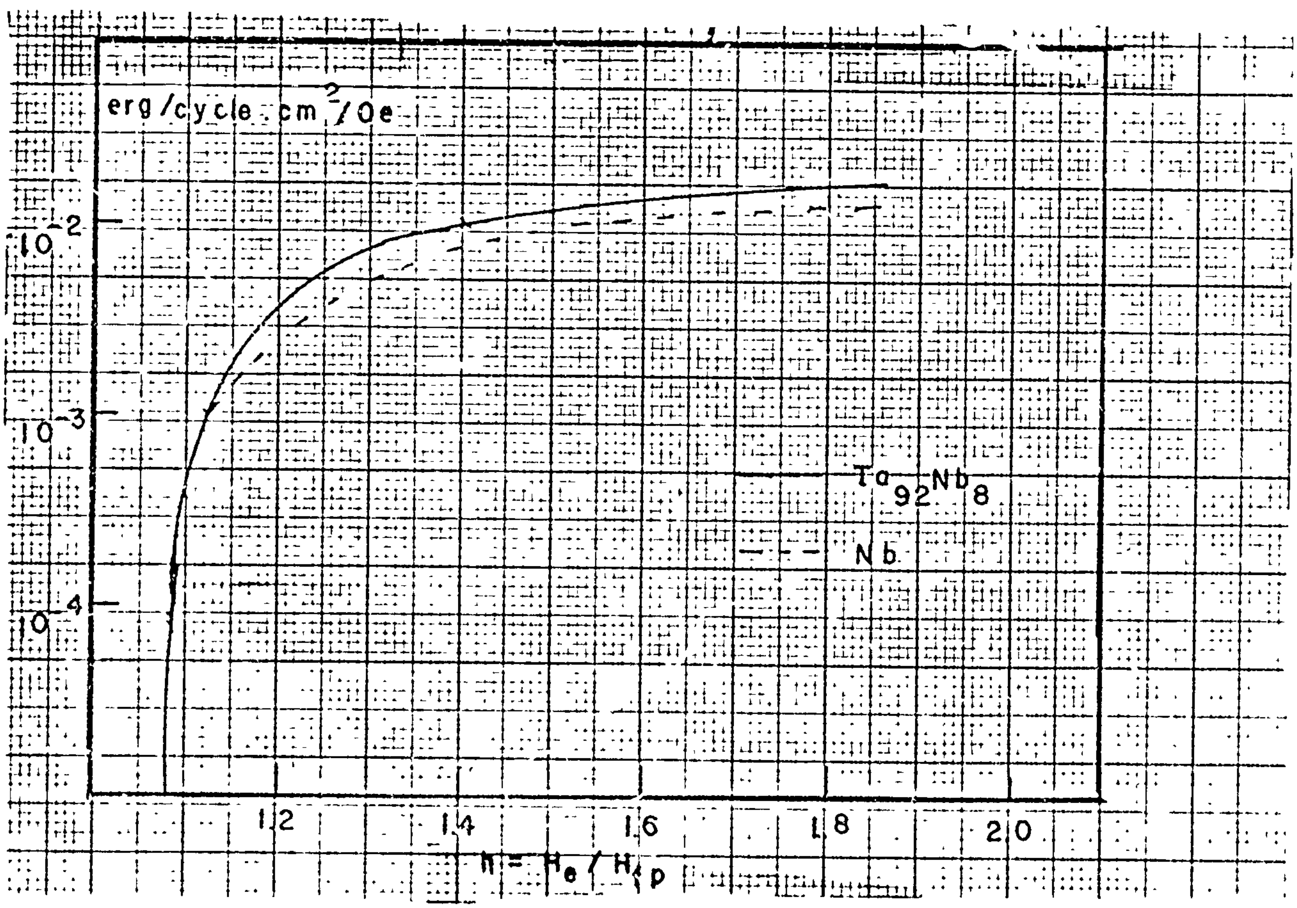

Fig. 2

These data are for a magnetically reversible sample of Nb_8Ta_{92} and Nb plotted as a function of reduced field $h = H_e/H_{FP}$ where H_e is the peak value of the applied sinusoidal magnetic field. Other alloys of this composition but of different amounts of pinning centers also behave in the above manner. Nb samples were also found to yield data which follow this curve quite closely. These observations led Furtado to infer the existence of a generalized law of ac losses which is applicable to reversible type II materials.

Dr. L. J. M. van de Klundert, Twente Technological University, Enschede, Netherlands reported on the behavior of Nb single crystals in ac fields. He and his coworkers at Twente University have developed an ac mutual inductance bridge technique which allows them to study the behavior of the higher harmonics of the response of the sample, i.e., they detect the complex permeability $\mu_k = \mu'_k + i\mu''_k$ where $k = 1$ to 99 denotes the harmonic. This work extends their earlier work in which only the fundamental response was measured. Dr. Klundert pointed out that proposed models describing magnetic behavior in magnetic fields below H_{c3} are based on static magnetization curves; thus, such models are limited to the response of the fundamental. Data for the higher harmonics result in an increased knowledge of the local (B,H) hysteresis loops, and from such studies more refined models should be forthcoming.

Klundert reported in detail results obtained from a study of the frequency and amplitude dependence of X and X" the in-and out-of-phase components of the magnetic susceptibility. He finds that the criteria established by H. J. Fink[8] for reversible magnetic susceptibility curves (χ vs H) [$dH/dt < \omega h$, where h and ω are the magnitude and frequency of the ac field and H is the applied dc magnetic field] are not sufficient. This work also shows that the value of the external field H_p at which losses appear, is a function of the amplitude of the superimposed ac field but not its frequency. Klundert concluded that the ac behavior of Nb can be qualitatively explained by consideration of the normal state resistivity, Hall coefficient, pinning of flux lines and surface screening currents.

Dr. Mitshurir Kudo of Hitachi, Ltd. Tokyo, Japan, reported on a detailed study of the ac losses in the Nb-Ti-Zr ternary system. The superconductivity of Nb-Zr-Ti has been reported previously by T. Doi et al[9]. In Kudo's work the percentage of one of the constituent elements was held constant. Critical current density in zero field

as well as the ac loss (20 to 500 Hz) per unit surface area per cycle, q_s, for a peak ac field of 1000 Oe were measured as a function of composition i.e., for the series $Nb_{.92-x}Zr_xTi_{.08}$ ($.30 < x < .45$); $Nb_{.60-x}Zr_{.40}Ti_x$ ($.04 < x < .12$) and $Nb_{.975-x}Zr_{.025}Ti_x$ ($.55 < x < .75$). The data show that q_s is a minimum at that value of x for which J_c is a maximum. For the alloys investigated the maximum J_c (•) values wer. $\sim 1 \times 10^6$ A/cm^2 with minimum q_s values $\approx 1 \times 10^{-6}$ J/cm^2-cycle. This work showed that the ternary alloys Nb-40Zr-8Ti had the lowest ac losses in NbZr rich alloys and these losses are considerably less than that of the binary Nb-Zr alloys. They also found that Nb-70Ti-2.5Zr has the lowest ac loss in the Nb-Ti rich alloys. These data are shown in Fig. 3a, 3 b.

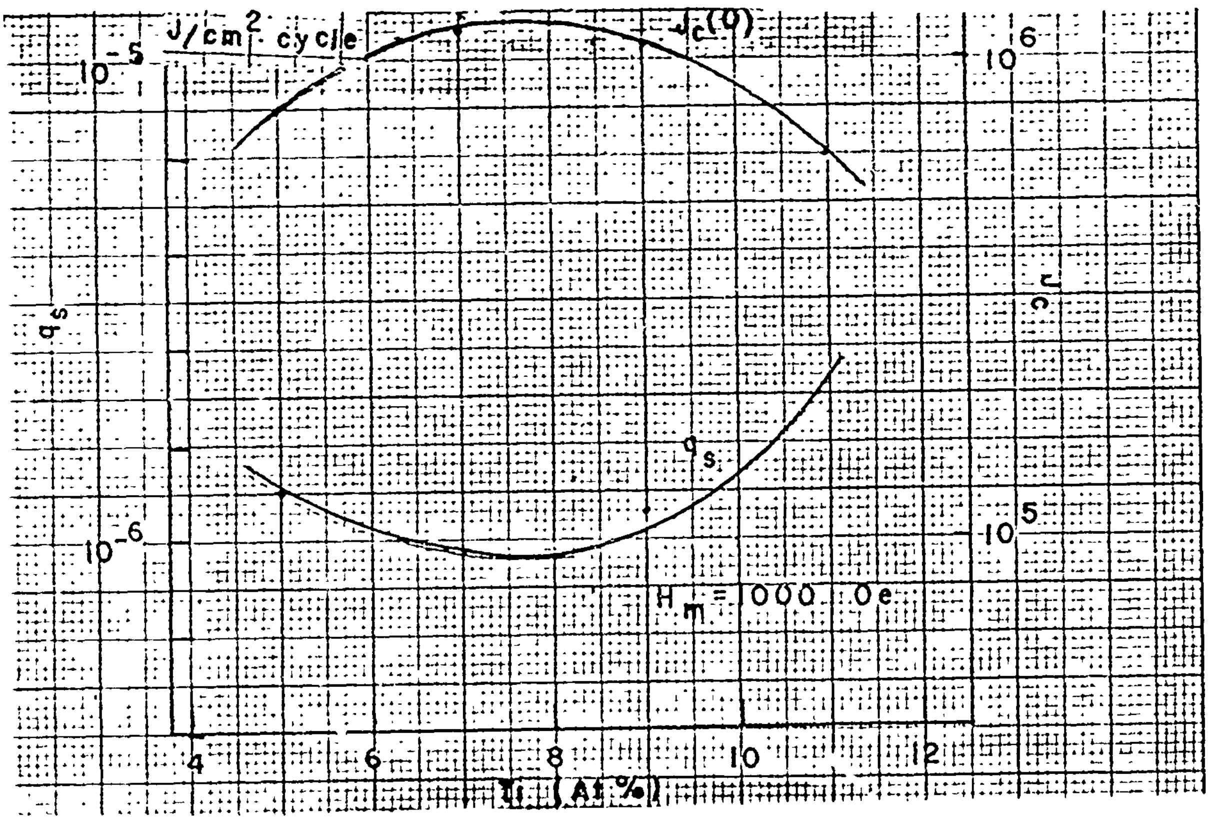

Fig. 3a

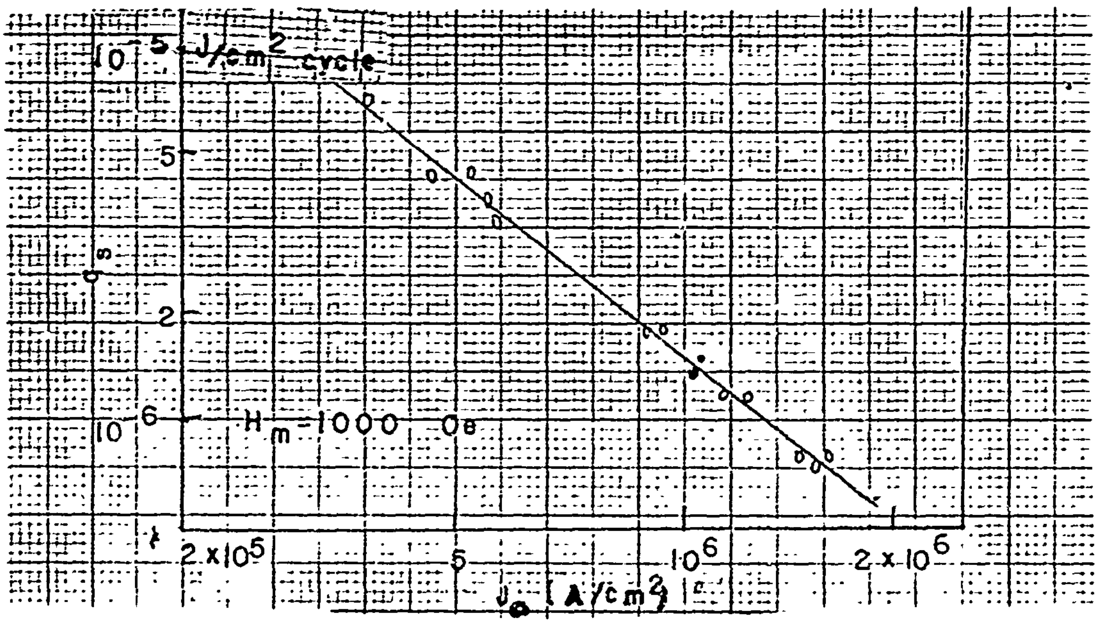

Fig. 3b

From this one sees that

$$q_s \approx \frac{H_m^{3.05 \sim 3.5}}{J_c(0)^{1.6}} \qquad (1)$$

where H_m is the peak surface field. Data were also presented on single core Nb-62.5Ti-2.5Zr and twisted multicore (Cu matrix) composite. The single core consisted of a superconducting core 0.25 mm in diameter copper clad (25 to 125 μm thick). The multicore conductors consisted of 16 to 19 filaments whose average diameter varied from 40 to 100 μm. The twist pitch was 2 to 20 mm in length.

Results with the composites showed that the total loss Q_1 can be represented by the sum of a linear and quadratic dependence on frequency. The latter is due to eddy current losses in the Cu while the former represents the losses in the superconductor. Similar results were observed for the multicore composites. See Fig. 4.

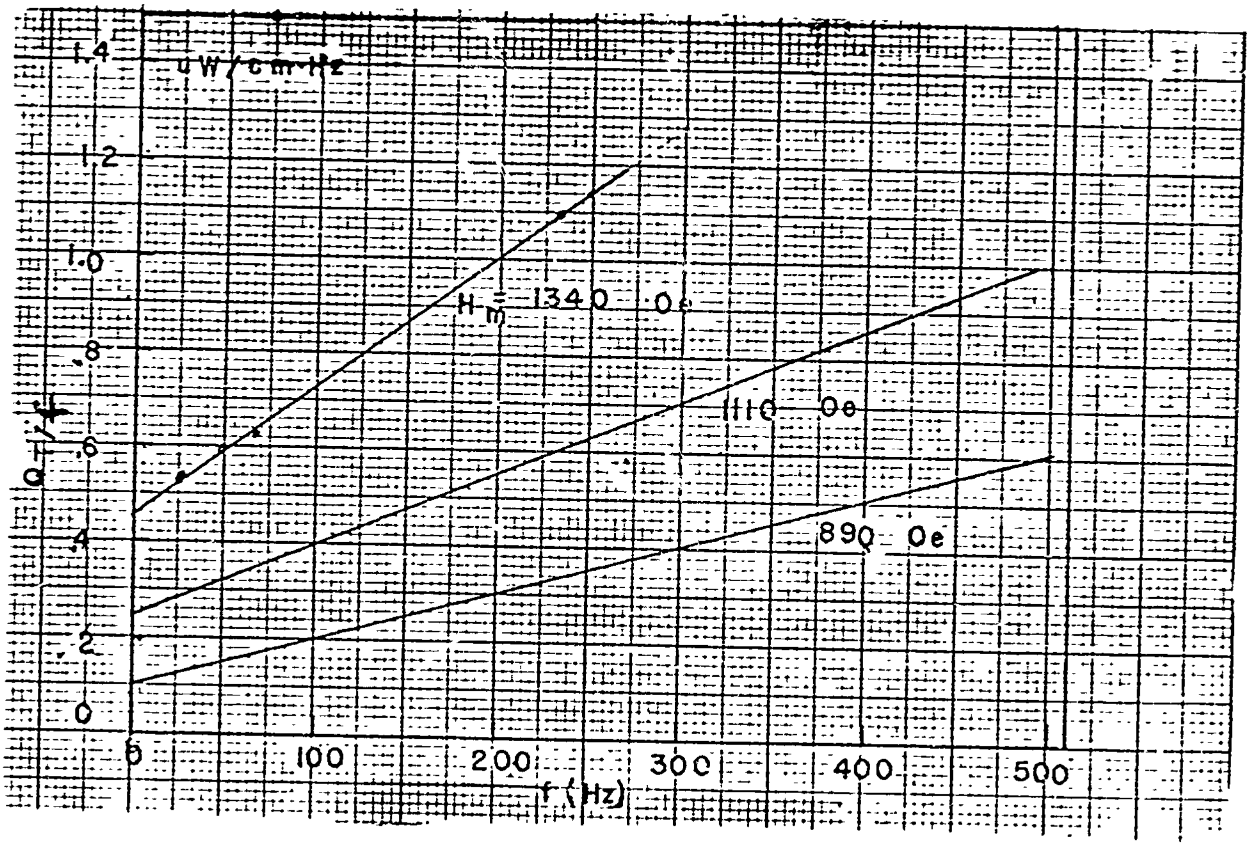

Fig. 4

These data, obtained by a helium boil-off technique, were stated to be in agreement (±5%) with magnetization results. It appears that the motivation for these studies in Japan is the considerable development work in progress to perfect superconducting composites for winding solenoids suitable for use in magnetic levitation of trains.

Dr. T. Pech reported on work going on at LCIE and LGEP in France, which is concerned with ac losses in superconducting composite conductors. The total loss in these composites are due to (1) a loss denoted as P_H due to the displacement of flux lines in the superconducting filaments and (2) eddy current losses in the normally conducting matrix which are denoted as P_J. Approximate expression for these two losses were given as

$$P'_H = \frac{2d}{3\pi} \int_{cycle} J_c (|B|) dB$$

Where d is the diamete·· of the filament, P'_H is the loss per cycle per unit volume of the filament and $J_c(B)$, the magnetic induction.

Eddy current loss, when the magnetic field is oscillating with a frequency f, is given as

$$P_{J1} = \frac{\sqrt{3}}{4\pi^2} l_p^2 \int_{cycle} \gamma (B) \cdot [\dot{B}]^2 \ dt$$

here ℓ_p is the twist pitch and $\gamma(b)$ is the electrical conductance between two neighboring filaments. This expression is derived on the basis of some simplifying assumptions such as $\ell_p > D$, the diameter of conductor, the filaments form a triangular lattice, etc. They also make arguments to show that when the interfilament spacing "a" is less than the electronic mean free path (mfp) in the matrix, the resistivity increases by a multiplicative factor of (mfp/a).

In this investigation ac losses were determined at 4.2K by measuring the area under the magnetization curve which was obtained by an electronic integration technique due to Fietz[10] in which an ac field of peak value B_m was varied with frequencies between 5×10^{-3} Hz and 2×10^{-1} Hz. These frequencies are well below power frequencies but are in the range of pulsed magnet applications. The experimentally determined losses were compared with the theoretical loss, P, per cycle per unit volume given by

$$P = (8/3\pi)\ Kd \int_0^{B_m} J_c(B)\ dB + \frac{4\sqrt{3}}{\pi\ 2} (\ell_p^2\ f)\ \ B_m^2 < \gamma(B) > \quad (I)$$

where K = fraction of composite volume occupied by the superconductor and $< \gamma(B) >$ is the mean value of γ during one cycle.

They found good agreement with composites having filament diameters ranging from 110 down to 4.8 µm, (our notes indicate that the filaments were NbTi) ℓ_p varying from 70 to 1.5 mm with both copper

and copper nickel matrices. To check these results they plotted P_{exp} vs $\ell_p^2 f$ which according to Eq.(4) should have an intercept equal to the ac losses in the filaments themselves.

The intercept yielded values in good agreement with Eq. I using experimentally determined $J_c(B)$ values. But in these latter measurements some adjustment of the criteria used to determine J_c was required (i.e., J_c was determined from that current which produced voltage drops along the sample of either 10^{-3} or 10^{-5} V/M.)

They concluded from this study: (1) for values of $B < 1.9T$ no magnetorestrictive effect is observable; (2) decreasing the diameter of the superconducting filament, d, to values as low as 4.8 μm has no effect on γ and (3) the electronic mfp in the Cu matrix for directions perpendicular to the filaments is less than 5 μm.

Dr. K. Yasukochi, Nihon University, Cheyoda-Ku, Tokyo, Japan reported on the work which he and several colleagues have done to study the effect of Cu cladding on the magnetic instability of NbTi composites. It appears that Yasukochi et al. feel that despite the large amount of work that has been done, the criterion for magnetic instabilities of Cu-clad composites is still not sufficiently understood. In this paper, magnetization data were reported on samples of Nb-50% Ti wires supplied by Vacuum Metallurgical Company. Isothermal magnetization curves were obtained at temperatures in the range of 2K to 4.2K for samples whose core diameter ranged from 90 to 405 μm. Data were obtained for both bare and Cu-clad wires with cladding thicknesses ranging from 30 to 115 μm. The Cu/NbTi ratio varied from 1.96 to 2.56.

In order to clarify the magnetic instability criterion they observed the dependence of a stability limiting field H_{fj}, as a function of temperature and metallurgical variables. See Fig. 5. Experimentally the flux jumps seen in Figure 5 were triggered by the sudden application of a small additional magnetic field. These results, as far as we can see, are in keeping with the generally expected behavior, i.e., Cu-cladding increases H_{fj} and the smallest diameter core 90 μm showed no flux jumps down to 2K.

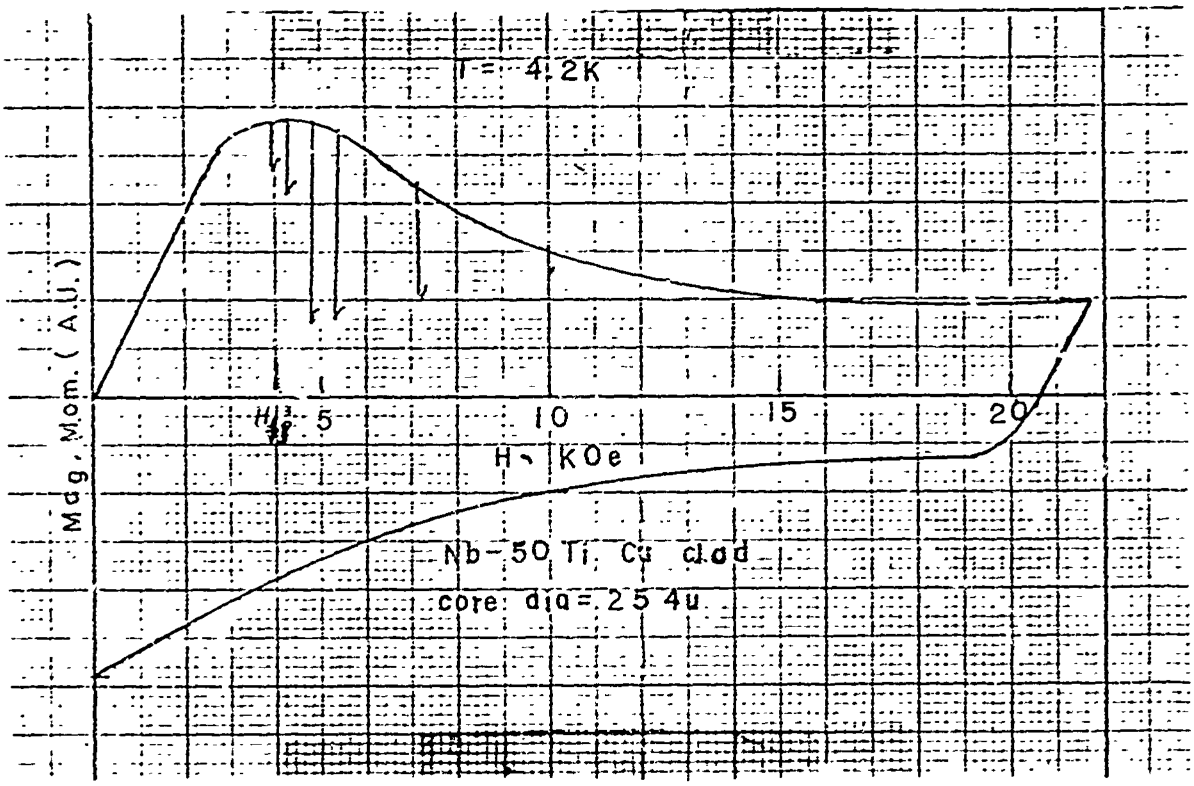

Fig. 5

Yasukochi et al.[11] extended the Schwartz and Bean critical state model[12] to obtain expressions for the cases where the magnetic diffusivity, D_m, is about equal to, and considerably less than the thermal diffusivity, D_t. The former case applies to the bare NbTi wires while the latter applies to the copper clad composites They concluded that the stability limit is quantitatively explained on the basis of the critical state model with $J_c B^2 = \alpha(T)$, $0 < \alpha \leq 1$ and provided due consideration is given to the relationship between D_m and D_t.

Dr. S. J. Wipf, Max Planck Institut für Plasmaphysik, Garching, Munich, W. Germany, reported on research he and Dr. M. Soell are doing on the flux flow properties of bare NbTi wire. Wipf emphasized that multifilament wires without a normal conducting matrix are desirable for ac applications. In general eddy currents induced in a normal matrix

due to ac magnetic fields are a problem in cryogenic applications. The ability of a superconducting filament to show little or no ac loss is related to its ability to sustain stable flux flow up to a certain voltage. Theory[13] tells us that stable flux flow exists provided

$$1/2\ J(\partial E/\partial J)\left|\partial J_c/\partial T\right| r \leq h \qquad \text{II}$$

where dE/dJ is the flux flow resistance

J_c is the critical current density

$J > J_c$ is current density causing the flux flow

r is the radius of the filament

h is the heat transfer coefficient to the helium

This equation was found to hold for samples with diameters of 11, 41, and 80 μm and for various J_c values. This latter parameter was varied from 10^6 to 10^5 A/cm^2 by the application of a magnetic field.

They found that if Eq. (II)was not obeyed, a wire composed of n filaments had an $I_c < nI_{cf}$ where I_{cf} is the critical current of the filament, but if it were obeyed, $I_c = nI_{cf}$; provided I or H is below a certain value. Better transposition of the filaments increases the value of I or H for which $I_c = nI_{cf}$.

D. Superconducting Magnets

As mentioned in earlier reports (ESN 25-4) one of the largest development programs concerned with superconducting magnets (denoted as S.C.M.) is associated with the field of high energy physics. At this ICEC meeting Dr. W. Heinz of Karlsruhe, West Germany reviewed the role which superconducting magnets can play in providing high energy physics with more powerful accelerators, bubble chambers, etc.

Heinz emphasized that the European superconducting magnet industry, as well as manufacturers of superconducting composites, are looking with great expectations towards replacing the conventional magnets in the CERN II accelerator, with superconducting ones, (see ESN 25-4 p. 126). This project concerns the Rutherford Laboratory

in England, Karlsruhe Laboratory in Germany and CEN (Saclay) in France. The interest in S.C.M. stems from the fact that conventional synchrotron magnets are limited in field strength to about 1.8T while superconducting ones should easily provide 4.5T. Thus, for the same ring diameter one should have a synchrotron of almost three times the energy. CERN II has a ring diameter of 2.2 km and when completed in 1976 will produce 300 GeV. S.C.M. will increase this to about 1000 GeV.

Synchrotron magnets used in pulsed operation have rise time of the order of a few seconds, therefore, $\dot{H} \approx 10^3\ O_e$/sec. This means that ac losses in S.C.M. must be minimized (1 watt of refrigeration at 4.2K requires about 1 kW of input power at room temperature). This accounts in part for the great interest in developing NbTi composites with low ac losses. The development of epoxy resins suitable for potting of the solenoid windings has led to the belief that S.C.M. which will maintain the required field tolerances, can be fabricated.

Work on pulsed S.C.M. has been going on since about 1961 and things look very encouraging. Heinz showed a schematic of a pulsed dipole S.C.M. being developed by Karlsruhe Laboratory (they work quite closely with the Siemens group at Erlangen). This S.C.M. which is designed for 6T with a rise time of from 1 to 20 sec, is scheduled for completion in two years' time.

In the case of CERN there are about 1000 magnets involved representing an overall length of some 5-km. Thus, one must think in terms of a 7-km Dwar and the refrigerator will have to produce 10 to 20W/meter of refrigeration at 4.2K. This represents a truly huge cryogenic plant of some 50 to 100 kW of refrigeration for the CERN 1000-GeV accelerator. The operating temperature may be 3.5K instead of 4.2K, but in any event the required refrigeration plant is larger than the capacity of any plant in existence today.

Heinz concluded that there have been many rapid developments in the last few years and one should be thinking in terms of 10T S.C.M.

The contributed session consisted of six papers. While we did not attend the entire session, we gather that nothing really new was reported, only steady progress along well-established lines.

At the Laboratoires de Marcoussis, Centre de Recherches de la CGE they have been experimenting with Al stabilized NbTi conductors and various coil designs including "potted" coils. M. Berthet reported

on S.C.M. fabricated from hollow Al stabilized NbTi conductors. Both systems employ closed cycle refrigerators. A 3T coil (80 cm room temperature aperture) is cooled to 4.2K while the other is a model coil, 50 cm aperture, cooled to 6K by circulating hyper-critical helium. It is rated for 5T.

One particularly interesting development was the use of multi-filament conductors and "potted" windings to fabricate an 8T coil at 4.2K which was magnetically stable so as to allow a field of 10.2T to be produced when operated at 2K. This improvement in field capability produced by operating at temperatures below 4.2K has been known for some time [14] (ORNL C-18-71).

Dr. P. E. Hanley reported on the Oxford Instrument Company's work concerned with measuring J_c of the NbTi conductors in the temperature range 1.9 to 4.2K in applied magnetic fields up to 10T. This work showed that a significant enhancement of J_c accompanies the decrease in temperature thus allowing S.C.M. with ratings up to 10T to be constructed. From a study of the $J_c(T)$ versus T curves for various field values, it appears that the best operating temperature turns out to be just below the lamda point of helium (2.18K). Another area where S.C.M. promises to play an important role is in the area of MHD power generation.

Japan has set MHD power generation as one of its national goals. Dr. Y. Aiyama of the Electrotechnical Laboratory, Lanaski, Tokyo reported on a collaborative effort involving colleagues at the Hitachi Works and at Nikon University concerned with the development of a S.C.M. for MHD work. They are currently constructing a 48 ton magnet (windings plus supports) out of Nb-Ti-Zr multi-clad strips of rectangular cross section 8 x 35 mm with a Cu/superconductor ratio varying from 6/1 to 23/1. The flat surfaces of the conductor are insulated by epoxy tapes and the conductors are cooled by liquid helium which is in contact with only the edges of the conductor. The cryostat has a 4000 liter liquid helium capacity.

The magnet is designed to produce a central field of 45 kOe in a fully stable operation over a rectangular room temperature aperture and should provide a uniform field over a volume 10 cm x 25 cm x 120 cm. Details of results on a test model were reported. It is noteworthy that the Japanese are using a ternary alloy instead of the more commonly used binary systems Nb-Ti and Nb_3Sn. One wonders whether this is a result of science or politics (or both).

E. Energy Storage and Transmission

This is a much discussed topic at any cryogenic or applied superconductivity conference as it is related to the world-wide energy crisis. We were of the opinion that the European effort in this area was larger and more advanced than that of the USA. However, from the discussions and presentations at this meeting one gathers that the European effort has not progressed very much in the last two years.

Dr. J. J. Went, Kema, Holland, presented a review paper "Why Cryogenics in the Power Industry", which brought out the following points: 1) To meet the increasing demands for electrical power the unit size of inservice generators has steadily increased in size since 1920. In Holland the largest unit in service today is 450 MW and at present a 600 MW unit is being evaluated. 2) Went feels that the unit size increase will not continue indefinitely but will level off at about 1000 or 1200 MW capacity. This latter figure is apparently felt to be the practical limit of conventional generators, and proponents of superconducting generators take over from there. 3) Transport of electrical energy is five times more expensive than transporting energy in the form of oil (and almost three times as expensive as natural gas). Clearly, then, it is more attractive to transport the oil or gas to the consumer region and to produce the electricity locally. Only the argument concerned with the lack of cooling water gives support to long distance transport of large amounts of electrical power. If such large transport of electrical power is required, cryogenic cables could be considered but alternative techniques should also be considered. One suggestion is to transport energy in the form of liquid hydrogen. In subsequent discussions with Dr. C. Marchetti, Head of the Materials Division, CCR, ISPRA, Italy, we were informed that hydrogen was indeed the master key to the energy market. (see EURO-SPECTRA Vol. X No. 4, Dec. 1971 p. 117-130).

The rational is this: nature supplies us with an abundant easy source of hydrogen, namely, water. It can be cheaply and safely piped and it is a clean fuel of many uses, therefore hydrogen can solve the energy crisis and the air pollution problem as well. Thus, there seem to be solutions to the energy crisis which do not include cryogenic or superconducting electrical transmission lines.

In the contributed session dealing with energy transmission Miss A. M. Schwab of the Electricité de France presented results of a study of resistive and superconducting cryocables which she and

Mr. L. Deschamps have recently performed. This paper dealt with preliminary design studies of ac resistive cryocables of 1000 and 3000 MVA as well as ac and dc superconducting cables of 3000 and 5000 MVA ratings. This study was restricted to flexible type cables cooled with liquid helium.

The ac resistive cables would be stranded Al conductor cooled with pressurized liquid nitrogen. The ac superconducting cable would be copper strips plated with Nb($T_c \approx 9.3K$). It would be cooled with hypercritical helium. The dc superconducting cable would use Nb_3Sn tapes ($T_c \approx 18K$).

Cryogenic design problems and their solutions as well as the overall economics of cryocables were discussed. It was emphasized that because of the costly solutions to termination problems, cryocables of under 10 km in length will probably never see service.

Since the cost of the cryogenic enclosure, refrigeration installations, etc., show little variation in relation to transmitted power, cables with ratings of 2000 MVA and higher have a definite economic advantage over conventional cables. While this study covered the usual details which such studies involve, one new aspect, as far as these writers are concerned, was the following: Schwab emphasized that if a cryocable failed because of conductor or cryogenic system failure, unavailability of the line would be quite lengthy, possibly 3 to 5 months depending on the type of cryocable employed. Consequently, a high degree of reliability is a must plus the fact that cryolinks be overequipped so as to cope with possible failure of one of the cryocables of the link. She concluded that more basic and applied work in this area is required and that it is quite possible that the French networks could need a superconducting line by 1990.

Dr. J. R. Barlett of Los Alamos Scientific Laboratory reported on a study which he and Dr. F. Edeskuty have done on the desirability of multi-use of cryogenic fluids in transmission lines. Apparently, this study was prompted by the belief that a space shuttle port would be located at White Sands, New Mexico. Although this seems no longer to be the case, the results of the study were felt to be of general interest and hence the presentation. The point is that a given cable should be able to transport electricity and liquid gases such as natural gas and hydrogen which could then be used as an additional energy source.

Dr. M. Rechowitz (University of Southampton, England), reported on the dielectric strength and dielectric loss of lapped paper and plastic insulation at cryogenic temperatures. These data are required for designing cryocables. He finds that Kraft paper impregnated with liquid nitrogen has a breakdown stress of 350V/mm (rms) which is comparable to that of conventional paperfoil insulation. However, impregnation with liquid helium leads to smaller breakdown stress. Dielectric losses at liquid nitrogen temperatures are still relatively high. Rechowitz is also doing thermal and electrical measurements on a 4 meter length of a flexible commercially stranded aluminum cable. The cable was hollow and standard 275kV insulation was employed.

Dr. J. P. Krebs (Laboratoires de Marcoussis, Centre de Recherches de la C.G.E., Route de Nazay-91 Marcoussis, France) presented an interesting paper on "Superconducting Devices for Energy Storage and Switching". Inductive energy storage appears useful for energies in the Megajoule range where the discharge times vary from about one millisecond to one second. Superconducting coils connected with a superconducting switch enable energies of 10^6 to 10^8 joules to be stored with almost zero loss. The energy can be released by fast discharge to provide high power pulses in the range of 10^6 to 10^9 watts. The main use for this type of high pulse generators are for controlled fusion research, power supplies for high energy lasers and various types of pulsed magnets and for gas discharge experiments in pulsed wind tunnels. Krebs reported on studies of the various components of a superconducting energy storage device: superconducting coil, power supply, superconducting switch, cryogenic environment, etc. He stated that the cost of an energy storage device made of a niobium-titanium superconducting coil is minimum for an induction of about 6 T and is nearly independent of the winding shape or energy level. By using intrinsically stable superconducting materials, it appears feasible to store very high energy densities, up to about 120 kilojoules per liter of material. By impregnating such a coil with good insulating material, it becomes possible to produce high voltage pulse of over 300 kV. Using niobium titanium multifilaments imbedded in a high electrical resistivity matrix of copper nickel, a superconducting switch capable of handling 25 megawatts was successfully operated. Routine laboratory use of superconducting generators to produce high power electrical pulses is reasonably certain in the near future.

F. Ultra Low Temperatures

The commercial availability of the Collins helium liquefier in the late 1940's gave birth to a tremendous expansion in the number of low temperature laboratories capable of performing research down to 1.2K. In a similar manner the late 1960's saw a large increase in the number of laboratories capable of performing research in the ultra

low temperature region (0.3K to 0.01K). This latter growth was due to the commercial availability of the He^3 - He^4 dilution refrigerater There is a growing list of European and American concerns which manufacture such refrigerators and to this list, the co-sponsor of ICEC-4 must now be added, i.e., Philips.

Prof. V. P. Peshkov, Institute for Physical Problems, Academy of Sciences, USSR, presented a review paper on the "Generation of Very Low Temperatures with Dilution Refrigerators and Their Measurements". Peshkov gave a review of the operating principles and factors which affect the low temperature limit of He^3 - He^4 dilution refrigerators. He discussed gravitational instability in refrigerators and stressed the importance of a vertical "loop" in the incoming line between the mixing chamber (cold region) and the condenser (He3). By stopping the circulation of the He^3 gas and "pumping" on the He^3 - He^4 liquid he produced temperatures as low as 3.5 mK.

Peshkov also mentioned the thermometry problem and stated that carbon resistance thermometers work quite well down to 8 MK. He discussed nuclear resonance thermometers (Fe^{57}), but these become relatively insensitive below about 20 mK. There were five scheduled contributed papers dealing with He^3 - He^4 refrigerators.

Dr. K. Raetz of Braunschweig, Germany and F. A. Staas of Philips discussed designs of heat exchangers. This subject remains of importance because heat exchangers are critical elements of He^3 - He^4 dilution refrigerators (indeed, one might say of any refrigerator). This is particularly so because of the existence of the Kapitza resistance which increases as $1/T^3$. He also discussed the construction of a new variant of the foil type heat exchanger. His exchanger consisted of copper foil 0.022 mm thick, 60 mm wide and 840 cm long. This foil was wound upon an OFHC copper bobbin, spacing between foil layers of 0.01 mm. The foil and bobbin fit inside a copper tube of 30 mm O.D. and 2-mm wall thickness. By the clever use of electron beam welding he 1) sealed the bobbin to the tube and 2) divided the heat exchanger into two parts with volume ratios of 3:1. This produced a heat exchanger of 9400 cm^2 and a surface of volume ratio of 1500. A He^3 - He^4 dilution refrigerator using five such heat exchangers produced temperatures somewhat below 50 mK.

Dr. P. A. Staas described "A New Type of Heat Exchanger for the He^3 - He^4 Refrigerator" which he and Dr. H. P. Severijns had developed at Philips. Staas pointed out that foil or sintered heat exchangers have flow impedances of the order of 10^7 cm^{-3}. Thus, a circulation rate of 2 x 10^{-4} mol/sec produces a viscous heating on the concentrated side (the incoming He^3) of 22 ergs/sec at 10 mK. This is equal to the cooling capacity of the mixing chamber at 10 mK. To overcome this problem one could use a parallel arrangement of heat exchangers, but this produces long cool-down times due to the increase in heat capacity of the system. To overcome this limitation the two counterflowing liquids were separated by thin 2 to 10 μm walls. This essentially overcomes the Kapitza resistance problem by allowing the phonons to tunnel through the separating barrier with sufficiently high efficiency at low temperature so as to effect a good heat exchange between the two fluids. Staas' heat exchanger is a sandwich structure of between 20 and 300 parallel layers of Cu foil which alternately separates the dilute He^3 from the concentrated He^3. The fluids flow in planar channels 40-100 μm thick. This heat exchanger has a low flow impedance 10^5 to 10^6 cm^{-3}, efficient heat exchange, small size and a short cooling time. The drawback seems to be that such exchangers are complicated to build and anyone contemplating using them should have a good supporting machine shop.

Dr. J. Wittig of Institut für Festkörperforschung Julich GmbH, FR Germany, discussed the He^3 - He^4 refrigerator which he and his co-workers built for use in high pressure experiments. The impetus for this work is to investigate the occurrence or nonoccurrence of superconductivity in the 4f elements under high pressure (~160kbar). Wittig stated that the magnetic cooling technique required the use of small pressure cells and he wished for a number of reasons, to use his standard pressure cell (3.5 kgm of BeCu alloy), therefore, the need for a dilution refrigerator. He mentioned the constraints such cells placed on the He^3- He^4 refrigerator, such as short cooling and warming times between room temperature and the very low temperatures (pressure can only be altered at room temperature). In his design the high pressure cell is bolted directly to the mixing chamber. He described in some detail the general physical makeup of his refrigerator which makes maximum utilization of the cold helium gas enthalpy to cool the bulky apparatus. To accomplish this a "cold valve" is used to let cold vapor (from the He^4 bath) into the chamber which contains the press, mixing chamber, etc. After the system cools to 10K, the valve (slim copper cone and polished steel seat) is closed and the space around the press, etc., is evacuated by pumping with a diffiusion pump.

The He^3- He^4 refrigerator uses concentric tube heat exchangers and has a refrigeration capacity of 100 erg/sec at 100 mk. The lowest temperature attained is 60 mk. Each helium transfer involves 10 liters of helium, five of which are collected and the holding time of the overall cryostat is 24 hours. Wittig is also reporting on the superconductivity of Lu and Hf under pressure at LT-13.

Dr. K. Weiss of Philips, reported on theoretical research being carried out with Dr. H. Haug aimed at developing additional information on the discrepancy between the theoretical and experimental value of the Kapitza resistance ($R_{exp} < R_{theor.}$). To do this they have carried out detailed calculations on the effect of surface dislocations present at the liquid-metal interface, and they believe such an effect lowers the Kapitza resistance and affects its temperature dependence.

Prof. Lacaze commented on the new type of heat exchanger used at Saclay; which is similar to the one discussed by Staas, but the thin foil was not copper but consisted of plastic. These plastic foils have a Kapitza resistance $\approx$ 1/10 of that of copper. Using this new heat exchanger with only 30 cm^2 of surface area, they attained a temperature of 10 MK. We believe this is a significant improvement in He^3-He^4 refrigerator technology. Philips, too, have used a plastic foil which is manufactured by Dupont under the name of Kyton. This is a registered trade name for a tough, high temperature cable insulation which is available in the form of very thin foils.

There was also a paper in a different session concerned with the best method to calibrate carbon resistor thermometers at ultra low temperatures. This paper by a group from Delft University, Netherlands, discussed the problem of thermal contact between the carbon resistor and the cerium magnesium salt pill. Magnetic cooling techniques as well as a He^3 - He^4 dilution refrigerator were utilized in this study which extended down to 15 mK.

G. Superconducting Levitation:

This is a topic which has had a special appeal to the cryogenic technologists ever since the low temperature physicists first floated a bar-magnet over a superconducting lead dish. This trick was used to

demonstrate the Meissner effect many years ago. Although magnetic levitation has been successfully employed in experimental apparatus such as wind tunnels, plasma confining machines, etc., present day interest by and large stems from the concept of high speed magnetically levitated trains.

Prof. Oshima of the University of Tokyo reviewed the program of Japanese National Railroad (JNR), the objective of which is to develop such a train by 1980. This program was initiated as a result of a 1970 study by the JNR which concluded that the best solution for the problem of high-speed ground-mass-transportation would be to use magnetic levitation provided by superconducting magnets and ground loops and a linear induction motor for the drive system. R & D work started in 1971 with the proviso that if the levitation work could not be developed in time, a more conventional wheel suspension system will be used with a resultant reduction in top speed from 550 km/hr to somewhat less than 400 km/hr (top speed of present systems is 210 km/hr).

Oshima stated that the proposed train will carry 128 S.C.M. (i.e., 16 carriages, each containing 8 S.C.M.). The cryogenic system will weigh about eight tons per carriage and the "track" will consist of loops or sheets of normal conducting metals. Test facilities have been developed by the JNR which permit dynamic testing of the levitation system up to speed equivalents of 100 km/hr.

In order to meet the 1980 development date, the final technical designs must be completed by 1975. The projected five-year R & D program, exclusive of salaries and testing land, will be about 100 million dollars. The project still in its infancy, but it is expected that efforts will be rapidly increased in the near future.

The contributed sessions were dominated by the Japanese with a report of a design study by Ford Motor Company, USA, and a preliminary evaluation study by the Cranfield Institute of Technology, England, rounding out the five-paper session.

Papers by a group of authors from the Toshiba R & D Center, Japan reported on tests conducted on S.C.M. wound with IMI's NbTi filamentary composites as well as NbTi multifilament conductors manufactured by CST. Magnetic and structural stability, magnetic shielding problems, lift forces, etc., were reported. It is interesting that no reports were given by any European companies, several of whom are quite active in this area.

H. Other Topics

There are several topics discussed in the sessions which are not mentioned in this report, so we will single out a few abstracts and/or sessions. The abstract of Dr. V. I. Kirschner of the Low Temperature Laboratory, Roland Eotvos University, Budapest, Hungary, gave details of the Nb_3Sn magnet and Be-Bronze bomb suitable for doing high pressure studies (resistance measurements) in Type II superconductors in fields up to 45 kOe and for pressures up to 20 kbar.

Of the three papers given in the cryobiology session, one had to do with the thermal properties of ice. The superconducting devices session contained reports on flux pumps and sensitive magnetometers. The session on electrical machinery contained five papers in which the various authors extolled the virtues of superconducting rotating machinery. A paper by Drs. Hadlow and Warme of the Electrical Research Association, Leatherhead, England considered reciprocating machines as well as rotating machines. They conclude that only the development of large turbo-generators offers commercial justification for the substantial development effort necessary for the realization of S.C.M.[2]

Mr.A.D. Appleton of International Research & Development Co., Newcastle, England, presented a paper concerned with dc machines in ship propulsion systems. This represented the only development work, as all the others concerned simply design studies of ac machinery.

Many more papers were presented dealing with purely cryogenic engineering problems and all aspects of refrigeration and heat transfer at cryogenic temperatures.

III. Reflections

As is usually the case, one returns from a large meeting with rather mixed emotions. However, in one respect our feelings are rather well defined and that is the sessions dealing with superconductivity applications were rather uninspiring; particularly disappointing was the apparent lack of any real progress in superconducting transmission lines as evidenced from a lack of papers by those industrial and governmental laboratories engaged in such developments. (See ESN 24-10, p 300; 24-12, p 390; 25-4, p 128.) There were no sessions dealing with superconducting developments with regard to accelerators, per se. (See proceedings of ICE-3). Plans with regard to the CERN conversion seems

to be where they were two years ago. However, research in developing superconducting magnets (SCM) suitable for pulsed synchroton applications has made slow steady progress, but one hesitates to say when such SCM's will be a reality.

Clearly, international meetings dealing with applications of superconductivity are being held at a rep titious rate which exceeds their need. This conclusion is based on the fact that one is hard put to come up with any new or important breakthrough reported at this conference, or at any applied superconductivity conference of the last two years.

As far as superconducting materials research is concerned, the ICEC meetings do not appear to be a forum for reports dealing with phase diagrams, etc., and should not be included in the program. This is based on the fact that the audience is not materials oriented except from the point of view of learning about engineering parameters such as ac losses, J_c, etc.

We were impressed by the sessions dealing with dilution refrigerators, and it was with a twinge of regret that one realizes that cryogenic engineers have moved into the last stronghold of the "Low Temperature Physicist" and are doing a very good job of removing the barriers to this once exclusive temperature range.

It was apparent that despite the best efforts of the organizers, one of the stated objectives of the conference was not met. This meeting with its parallel sessions did not really provide the opportunity for workers from various disciplines to meet and discuss problems of mutual interest. Parallel sessions on closely related topics served to frustrate several attendees. Individual plenary sessions contained widely divergent subjects, e.g., dillution refrigerators and cryobiology. This is not to say that this conference was not well organized and conducted, for it was. It is just that "cryogenic engineering" is too broad a field for a single meeting.

The proliferation of meetings, which a scientist involved with superconducting technology, can say he should attend has reached the point of diminishing returns, (see Appendix C). Real progress is not being made at a rate which justifies biennial conferences, especially in view of the fact that there are so many biennial conferences, they come up in various forms about every six months or so. Clearly ICEC-4 suffered by being held only three weeks after the Applied Superconductivity Conference at Annapolis, Maryland.

APPENDIX A

UNIVERSITIES IN THE NETHERLANDS

1. Technological University of Eindhoven, Founded in 1956, student body 4000; faculty 120.

2. Delft University of Technology, Founded in 1842. Student body: 9500; faculty 200.

3. Twente Technological University, Founded in 1961. Student body 1800;

In addition to the above three technical universities, the Netherlands has the following major universities:

4. University of Amsterdam. Founded in 1877. Student body 18,000; faculty 250.

5. University of Groningen. Founded in 1614. Student body 12,000; faculty 200.

6. University of Leyden. Founded in 1575. Student body 11,000; faculty 200.

7. Catholic University of Nijmegen. Founded in 1923. Student body 10,000; faculty 150.

8. University of Utrecht; founded in 1636. Student body 17,000; faculty 280.

9. Free University (Amsterdam) founded in 1880. Student body 6000; faculty 100.

This list is an impressive number of universities considering the total population of the Netherlands is some 13 million.

APPENDIX B

List of Papers - Titles and Authors by Session & Subject

Trends in the use of very low temperature refrigeration.

A. Lacaze, Centre de Recherches sur les tres basses Temperatures, Grenoble, France

Why Cryopumping? H. G. Nöller
Leybold Heraeus GmbH & Co, Germany

Helium conservation in the USA, W. H. Hogan
Cryogenic Technology Inc., USA

Project of magnetically suspended train in Japan, K. Oshima
University of Tokyo, Japan

Why cryogenics in power industry?, J. J. Went
SEMA, The Netherlands

Generation of very low temperatures with dilution refrigerators and their measurement, V. P. Peshkov, Academy of Sciences, USSR

Cryobiology, D. E. Pegg
Clinical Research Center, Harrow, England

Superconducting synchrotrons for high energy physics, W. Heinz
Kernforschungszentrum, Karlsruhe, Germany

Refrigeration: General

A small neon refrigerator, W. Koeppe
KFA, Jülich, Germany

Refrigerator without moving parts at low temperature able to cool down to 90-100 K, E. Carbonell, P. Chovet, C. Johannes, D. Marinet, P. Solente
CEC, L'AIR Liquide, France

Helium liquefier operating continuously with large impurities
R. Kneuer, K. Petersen, A. Stephan, Linde AG, München, Germany

Gas bearing cryogenic expansion turbines: application to a refrigerating plant delivering 10 kW at 25 K., J. Gass, J.C. Villard, D. Marinet, P. Solente
CEC, L'AIR Liquide, France

The turbo-expander as a cryogenic tool in the oil and gas industry,
H. W. L. Wulff, Fluor Nederland NV

Simplified cryogenic reciprocating expansion engine
G. Claudet, J. Verdier; C.E.N. Grenoble, France

Refrigeration: Regenerative Machines

Experiments on a two-stage Stirling cryogenerator with unbalanced regenerators, A. Mijnheer
Philips Research Laboratories, The Netherlands

Two-stage expansion engine with differential piston, I. B. Danolov, V. T. Kovatchev, Academy of Sciences, USSR

Small capacity valveless piston expansion engine type cryorefrigerator
B. B. Parulekar, K. G. Narayankhedkar, Indian Institute of Technology, India

Heat transfer and flow friction characteristics of dense mesh wire screen regenerator matrices at cryogenic temperatures, G. Walker, W.K. Wan
University of Calgary, Canada

A theoretical solution of the shuttle heat transfer problem, J. B. Harness, P.E.L. Newman, University of Bradford, England

Refrigeration: 1, 8 Systems

Cryogenic engineering aspects of the superconducting accelerator at Karlsruhe, P. Flécher, Kernforschungszentrum Karlsruhe, FR Germany

Cryogenic systems for the superconducting linear accelerator system and particle separator projects, W. Barth, W. Herz, L. Hütten, H. Katheder, W. Lehmann, F. Spath, G. Winkler
Kernforschungszentrum Karlsruhe, Germany

He-II cryostat for a superconducting particle separator, K. Ruppert
Linde AG, München, Germany

The use of an expansion ejector in a 5-W refrigerator at 1,8 K, J. Mulder
Philips Research Laboratories, The Netherlands

Refrigeration and Thermometry

Applications of gamma-ray thermometry at low temperatures
W. D. Brewer, E. Klein, B. H. Rosenthal, P. Steiner
Freie Universität, Berlin, Germany

Osmotic pressure secondary thermometer for dilution refrigerators
D. Bloyet, A. Chozlan, P. Piejus, M. Sudraud, E.J.A. Varoquaux, D. Le Fur
Institut d'electronique fondamentale, Paris, France

Distillation of helium isotopes, W. R. Wilkes
Monsanto Research Corporation, USA

Refrigerator for the 20 K region with a $LaNi_5$-hydride thermal absorption compressor for hydrogen, H. H. van Mal, A. Mijnheer
Philips Research Laboratories, The Netherlands

Some practical data on desorption cooling, J. G. Daunt, C.Z. Rosen
Stevens Institute of Technology, USA

Dilution Refrigerators

Heat exchangers for dilution refrigerators, K. Raetz
Physikalische-Technische Bundesanstalt, Braunschweig, Germany

A new type of heat exchanger for the He^3 - He^4 refrigerator
F. A. Staas, A. P. Severijns, Philips Research Laboratories, The Netherlands

Influence of a thin surface-dislocation layer on the Kapitza resistance,
H. Haug, K. Weiss, Philips Research Laboratories, The Netherlands

A dilution refrigerator for nuclear dynamic polarization
T. O. Niinikoski, P. Weymuth, CERN, Switzerland

A dilution refrigeration cryostat for high pressure experiments,
B. Stritzker, J. Wittig, H. Wühl, K.F.A., Julich, Germany

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APPENDIX C - MEETINGS - 1972

The proliferation and frequency of meetings in cryogenic engineering and low temperature physics is becoming a serious problem in the US both to researchers with severely limited travel budgets and to government funding agencies which, with each new year, have diminishing amounts of funds to support travel outside the US. In 1972 we are aware that the following meetings were held in these fields:

1. Meeting on Supercritical Helium, April, Leatherhead, Surrey, England

2. Applied Superconductivity Meeting, May, Annapolis, Maryland,

3. Europhysics Study Conference on Thermometry and Thermal Contacts below 50 MK, April, Albé, France

4. European Physical Society Conference on Low Temperature Physics, April, Freudenstadt, Germany

5. Cryogenic Engineering Conference, August, Boulder, Colorado

6. Thirteenth International Conference on Low Temperature Physics, August, Boulder, Colorado

7. Conference on Intercalated Superconductors, August, Monterey, California

8. Meeting on Synchronous Machinery using Superconducting Field Windings, August, Cambridge, Mass.

9. Third International Conference on Liquefied Natural Gas, September, Washington, D. C.

Unlike the rapid advancing fields of cryogenic engineering, and applied superconductivity, basic research in low temperature physics may have passed its zenith. Much of what formerly used to be fundamental research now tends towards applications. Basic research at low temperatures appears to be contracting in scope, and it is anticipated that the large LT conferences which are now held biennially will in the future be held every third year. It would facilitate the exchange of information and reduce travel expenses if cryogenic engineering and low temperature research conferences could be held in tandem in the same country.

APPENDIX D

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